Low-Energy Cross Section Measurements of ^{12,13}C(p,γ) Deep Underground at LUNA

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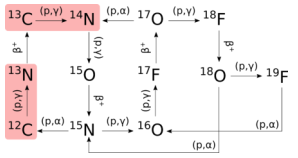
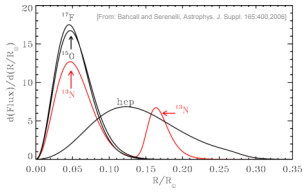
Abstract Systematic studies of radiative proton capture on ^{12}C and ^{13}C have been conducted deep underground at the Laboratory for Underground Nuclear Astrophysics (LUNA), located at INFN-LNGS (Italy).
Data for the reaction cross section were obtained down to new record-low energies, and are presented here.

Radiative Proton Capture on Carbon

The capture reactions ^{12}C(p,γ)^{13}N and ^{13}C(p,γ)^{14}N are both part of the CNO cycle. Neutrinos from the decay of ^{13}N contribute to the CNO neutrino flux observed from the Sun, where nuclear cross sections determine the radial profile of neutrino emission.

The observable abundance ratio of ^{12}C/^{13}C may serve as a probe for mixing mechanisms in AGB stars, requiring precise knowledge of both capture reactions to reduce uncertainties from nuclear physics.





Experimental Conditions

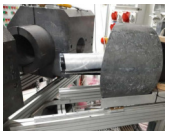
The LUNA-400 accelerator allows for terminal voltages up to 400 kV, providing beams with low energy spread and excellent stability. Proton beams with intensities of up to 300 μA were used for this experiment.

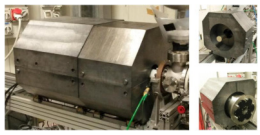
The underground location of LUNA at the Gran Sasso National Laboratory, shielded from cosmic backgrounds, provides the environment for low-background experiments with high sensitivity.

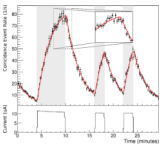
Detection Techniques

Two detector setups were used: a HPGe detector for gamma-ray spectroscopy, and a segmented 4π BGO detector for high-efficiency total absorption spectroscopy and decay counting of ^{13}N produced by ^{12}C(p,γ).

All setups were shielded by 10-15 cm of lead, for suppressing environmental gamma-ray backgrounds.



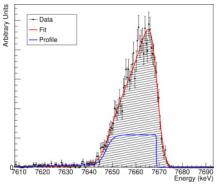


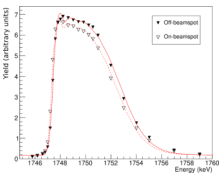


Targets

Evaporated thin targets (natural carbon, or enriched in ^{13}C) on Ta backings, and thick graphite targets (nat. carbon), were used.

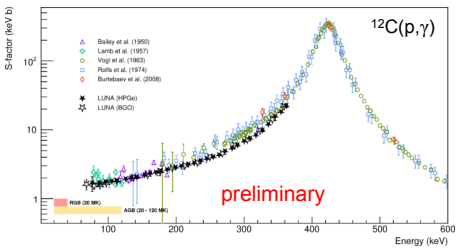
Thin target properties were characterized and monitored in situ with the line width and shape of the direct capture peak for ^{13}C in a HPGe detector, as well as ex situ by scanning a narrow resonance in ^{13}C(p,γ) at the Institute for Nuclear Research (Atomki, Debrecen).

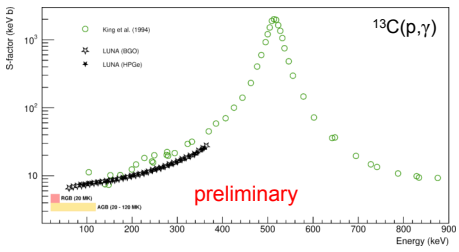




Preliminary Results

Data Analysis for both reactions results in compatible sets of S-factor data across different targets and detection techniques at LUNA-400.





Total S-factors are shown. The absolute scale of the new data sets, relative to previously existing literature data sets is currently under study for both reactions, aiming for a comprehensive R-matrix fit with AZURE2.

Summary

Experiments at LUNA-400 resulted in cross section data for both reactions, down to (center-of-mass) 80 keV for ^{12}C, and 60 keV for ^{13}C. Different target and detection setups were used to limit systematic experimental uncertainties.

They provide directly measured cross section data in the astrophysical region of interest, e.g. for AGB stars. The publication of this data is in preparation.

A complementary measurement of ^{12}C(p,γ) at higher energies has been conducted shallow-underground at the Felsenkeller laboratory to further study normalization of these data sets, using an array of HPGe detectors; data from this experiment is currently being analyzed.

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The work of A. Boeltzig was supported by the European Union (project no. 101008324).

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